

U. S. NAVAL AMMUNITION DEPOT
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From: Commanding Officer, U. S. Naval Ammunition Depot, Crane, Indiana
To: National Aeronautics and Space Administration, Goddard Space Flight Center, Electrochemical Power Sources Section (636.2), Space Power Technology Branch, Greenbelt, Maryland 20771

Subj: Report QE/C 65-123; Electrochemica Corporation, Four Ampere-Hour Silver Cadmium Cells Program; forwarding of

Ref: (a) NASA Defense Purchase Request No. S-23404-0

Encl: (1) Five copies of Report QE/C 65-123

1. In compliance with reference (a), enclosure (1) is forwarded for information and retention.

E. R. PETTEBONE

[Signature]
V. YEAGER
By direction

Copy to:
BUWEPS (FQ-1)
Electrochemica Corporation (Dr. Morris Eisenberg), Menlo Park, Calif.
NASA, Scientific and Technical Information Facility (NASA REP RQT-202238),
P. O. Box 5700, Bethesda, Maryland 20014

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Program For ElectrochemicaFour Ampere-Hour Silver Cadmium Cells1. Battery Identification.

a. The battery consists of 10 rectangular sealed cells connected in series. Each cell is encased in an individual plastic container. The cells, developed by the Electrochemica Corporation, Menlo Park, California, were nominally rated at four ampere-hours. These cells were mounted in a rigid fixture, by Goddard Space Flight Center, to prevent high pressure expansion, and were received in a discharged condition.

2. Test Parameters.

a. The battery was scheduled for 100 continuous cycles, at each of three temperatures, at room ambient pressure. The three test temperatures were $25 \pm 2^\circ \text{C}$, 0°C , and 40°C . Each cycle of 24 hours duration consisted of a 1-hour discharge followed by a recharge for 23 hours.

b. The discharge capacity was specified at 62.5 percent of the rated capacity in ampere-hours. This was found to be 2.5 ampere-hours, equivalent to a rate of 2.5 amperes for the 1 hour of discharge per cycle.

c. The charge rate was specified to be limited to 120 milliamperes while limiting the on charge voltage to 1.50 volts per cell average at each of the three temperature conditions.

d. The battery was continuously monitored. All charge and discharge currents and terminal voltages were recorded. In addition, terminal voltage, currents, cell voltages and temperatures were manually recorded every seventh cycle.

e. The voltage plateau level of this battery at the specified rate, in an ambient of $25 \pm 2^\circ \text{C}$ was lower than that of other silver cadmium cells of like capacity and discharge rate tested at this facility. This would necessitate the use of one or more cells to achieve the same battery voltage as that of the other silver cadmium cells. For this reason, cycling tests at 0°C and 40°C were omitted at the request of Goddard Space Flight Center representative (Mr. T. J. Hennigan).

3. Test Procedures.

a. The battery was placed in a temperature chamber, maintained at an ambient of $25 \pm 2^\circ \text{C}$, on a plexiglass pedestal, isolating it from all thermally conductive surfaces. Thermocouples were fastened to the positive terminals of all 10 cells. The cells were monitored in the following order: (1) Manufacturer's No. 116, (2) No. 121, (3) No. 120, (4) No. 115, (5) No. 117, (6) No. 123, (7) No. 122, (8) No. 118, (9) No. 124 and (10) No. 119. A thermocouple was also placed in the chamber to measure the chamber ambient temperature.

b. The battery was first given a constant current charge of 200 milliamperes to a terminal voltage of 15.8 volts. The battery accepted 4.45 ampere-hours.

c. Following a 24-hour open circuit stand, the battery was started on the 100 continuous cycles of discharge at 2.5 amperes for 1 hour followed by a recharge for 23 hours, limiting the current to 120 milliamperes and the voltage to 1.50 volts per cell.

d. Because of low end of discharge voltages, the voltage limit, starting with cycle 5, was increased to 1.55 volts per cell. This was approved by Goddard Space Flight Center representative (Mr. T. J. Hennigan).

e. Again, because of low end of discharge voltages, the charge portion of cycle 39 was continued beyond the usual 23 hours at a constant current charge rate of 200 milliamperes. Each cell was removed from the charging circuit when its on charge voltage reached 1.60 volts. Four of the cells were above 1.60 volts at the end of the regular charge period, whereas the remaining cells required from 10 minutes to 1 hour additional charge at the higher rate to reach 1.60 volts per cell.

f. The on charge voltage limit of 1.55 volts per cell average was maintained from cycle 40 through cycle 101.

g. The 1-hour 2.5 ampere discharge of cycles 102 through 117 was followed by a 23-hour recharge, current limited to 240 milliamperes and voltage limited to 1.58 volts per cell average.

(1) Cell number 115 was removed at the end of discharge of cycle 114 because of voltage reversal and returned to Goddard Space Flight Center for examination.

h. The 1-hour 2.5 ampere discharge of cycle 118 was followed by a 30-day float charge limiting the current to 240 milliamperes and the voltage to 1.50 volts per cell average. At the end of the 30-day float charge, the battery was discharged at a rate of 2.5 amperes to an individual cell voltage of 0.6 volts. The capacities of cell 1 through cell 10 (omitting cell 4 that was removed from test) were 5.68, 5.38, 5.95, 4.50, 5.43, 5.50, 6.20, 5.80 and 5.70 ampere-hours respectively.

4. Discussion.

a. Cycles 1 through 115 at $25 \pm 2^\circ$ C.

(1) With 62.5 percent depth of discharge, the battery accepted more ampere-hours of charge than dissipated on discharge. The only exception to this was cycle 1. With each increase of the voltage limit, the ampere-hours of charge increased slightly, thereby lowering the ampere-hour and watt-hour efficiencies.

(2) Ampere-hour and watt-hour efficiencies are shown in Table I.

(3) Beginning of discharge, end of discharge and end of charge current values and voltage readings are shown in Tables II, III and IV respectively.

(4) Because of the orbit length and the battery being operated in a chamber of moving air, the cell temperature rise at the end of discharge or end of charge never exceeded 1° C above the ambient. This temperature measurement was taken on the positive terminal of each cell.

(5) There was no noticeable leakage of any of the cells at any point during the test.

TABLE I
62.5 PERCENT DEPTH OF DISCHARGE

CYCLE	PER CELL VOLTAGE REGULATED	CURRENT LIMITED AMPERES	AMPERE- HOUR DISCHARGE	AMPERE- HOUR CHARGE	AMPERE- HOUR EFFICIENCY	AVERAGE VOLTAGE DISCHARGE	AVERAGE VOLTAGE CHARGE	WATT- HOUR OUTPUT	WATT- HOUR INPUT	WATT- HOUR EFFICIENCY
1	1.50	0.120	2.50	1.65	151.9	10.48	14.60	26.2	23.6	111.0
18	1.55	0.120	2.50	2.47	101.2	10.12	13.75	25.3	33.5	75.6
32	1.55	0.120	2.50	2.65	94.3	10.12	14.14	25.3	37.3	67.8
46	1.58	0.120	2.50	2.59	96.5	10.00	14.25	25.0	36.7	68.2
58	1.58	0.120	2.50	2.58	96.8	10.04	14.54	25.1	37.3	67.2
73	1.58	0.120	2.50	2.60	96.3	9.88	14.55	24.7	37.5	65.8
87	1.58	0.120	2.50	2.73	91.5	10.08	14.46	25.2	39.5	63.9
94	1.58	0.120	2.50	2.62	95.3	10.00	14.39	25.0	37.5	66.6
108	1.58	0.240	2.50	2.90	86.1	9.96	15.45	24.9	43.9	56.7
115	1.58	0.240	2.50	2.76	90.5	9.00	13.92	22.5	37.6	59.8

TABLE II

BEGINNING OF DISCHARGE

CYCLE NUMBER	CURRENT (AMPERES)	TERMINAL VOLTAGE	CELL VOLTAGES									
			1	2	3	4	5	6	7	8	9	10
1	2.5	12.10	1.22	1.22	1.22	1.24	1.21	1.19	1.24	1.24	1.17	1.20
5	2.5	10.20	1.02	1.03	1.02	1.03	0.99	1.02	1.02	1.02	1.02	1.02
10	2.5	11.00	1.06	1.03	1.04	1.14	1.02	1.04	1.10	1.06	1.04	1.02
18	2.5	10.90	1.09	1.01	1.04	1.06	1.00	1.04	1.09	1.04	1.04	1.00
20	2.5	10.36	1.08	1.01	1.03	1.06	1.00	1.08	1.07	1.06	1.05	1.00
25	2.5	10.20	1.03	1.01	1.01	1.04	1.00	1.02	1.04	1.04	1.04	1.01
32	2.5	10.03	1.04	1.01	1.01	1.04	1.00	1.02	1.04	1.03	1.02	1.00
35	2.5	10.15	1.02	1.00	1.00	1.04	0.99	1.00	1.05	1.04	1.01	1.01
40	2.5	10.20	1.03	1.02	1.01	1.04	1.02	1.01	1.04	1.04	1.02	1.01
46	2.5	10.20	1.06	1.01	1.01	1.04	0.98	1.09	1.04	1.02	1.01	1.01
50	2.5	10.40	1.06	1.01	1.01	1.04	1.00	1.03	1.01	1.00	1.02	1.01
55	2.5	10.51	1.11	1.05	1.07	1.16	1.05	1.13	1.01	1.01	1.06	1.02
58	2.5	10.35	1.12	1.03	1.04	1.05	1.02	1.13	1.00	1.01	1.05	1.01
65	2.5	11.10	1.16	1.10	1.10	1.14	1.10	1.13	1.00	1.00	1.06	1.01
70	2.5	10.95	1.13	1.15	1.11	1.11	1.11	1.12	0.99	1.03	1.06	1.02
73	2.5	10.40	1.14	1.12	1.09	1.18	0.96	0.94	1.00	1.01	1.02	1.02
80	2.5	10.78	1.17	1.14	1.12	1.19	0.96	1.15	0.99	1.04	1.06	1.03
87	2.5	11.47	1.21	1.20	1.13	1.19	1.14	1.13	1.18	1.08	1.14	1.14
90	2.5	11.25	1.21	1.19	1.18	1.10	1.08	1.14	1.15	1.04	1.10	1.14
94	2.5	11.05	1.19	1.19	1.12	1.16	1.04	1.09	1.08	1.12	1.11	1.06
101	2.5	11.20	1.18	1.17	1.19	1.18	1.00	1.07	1.14	1.13	1.13	1.05
108	2.5	11.39	1.20	1.20	1.17	1.20	1.04	1.05	1.10	1.11	1.01	1.13
115	2.5	10.60	1.22	1.11	1.21	*	1.17	1.08	1.20	1.16	1.10	1.19

* Cell 4 removed at cycle 112.

TABLE III

END OF DISCHARGE

CYCLE NUMBER	CURRENT (AMPERES)	TERMINAL VOLTAGE	CELL VOLTAGES									
			1	2	3	4	5	6	7	8	9	10
1	2.5	10.02	1.01	1.01	1.01	1.02	1.01	1.01	1.01	1.01	1.00	1.01
5	2.5	9.40	0.93	0.96	0.97	0.99	0.96	0.96	0.85	0.88	0.96	0.96
10	2.5	10.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18	2.5	10.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	2.5	10.00	0.98	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.00
25	2.5	10.02	0.99	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.00
32	2.5	9.98	0.98	1.00	1.00	1.02	0.99	0.98	1.00	1.00	1.00	1.00
35	2.5	9.91	0.97	1.00	1.00	1.01	0.99	0.97	0.99	0.99	0.99	1.00
40	2.5	9.82	0.95	1.00	1.00	1.01	0.97	0.89	1.00	0.99	1.00	1.00
46	2.5	9.80	0.95	0.99	0.99	1.02	0.99	0.89	1.00	1.00	0.99	1.00
50	2.5	9.89	1.00	1.01	1.00	1.01	0.98	0.66	1.00	1.00	0.99	1.00
55	2.5	9.70	0.98	0.99	1.00	1.02	0.99	0.72	1.00	1.00	1.00	1.00
58	2.5	9.70	0.97	0.99	1.00	1.01	0.99	0.77	1.00	0.98	0.99	1.00
65	2.5	9.80	0.96	0.98	0.98	1.00	0.97	0.90	0.99	0.98	0.98	0.99
70	2.5	9.80	0.96	0.99	0.98	1.00	0.97	0.97	0.99	0.99	0.99	1.00
73	2.5	9.50	0.96	0.98	0.99	1.00	0.98	0.63	1.00	0.98	0.99	1.00
80	2.5	9.69	0.97	0.98	0.98	0.99	0.98	0.85	0.98	0.94	0.98	0.99
87	2.5	9.65	0.92	0.99	0.99	0.94	0.98	0.87	0.99	0.92	1.00	1.00
90	2.5	9.75	0.96	0.99	0.99	0.97	0.98	0.91	0.99	0.90	0.99	0.99
94	2.5	9.65	0.90	0.99	0.98	0.96	0.98	0.94	0.97	0.93	0.98	0.98
101	2.5	9.80	0.98	0.98	0.98	0.97	0.98	0.96	0.99	0.94	0.98	0.99
108	2.5	9.60	0.96	0.97	0.98	1.00	0.95	0.90	0.96	0.92	0.96	0.97
115	2.5	8.64	0.97	0.97	0.98	*	0.96	0.85	0.98	0.96	0.96	0.98

* Cell 4 removed at cycle 112.

TABLE IV

END OF CHARGE

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CYCLE NUMBER	CURRENT (AMPERES)	TERMINAL VOLTAGE	CELL VOLTAGES									
			1	2	3	4	5	6	7	8	9	10
1	0.027	15.00	1.50	1.51	1.51	1.51	1.51	1.50	1.48	1.48	1.51	1.51
5	0.120	14.98	1.49	1.50	1.50	1.49	1.50	1.50	1.49	1.49	1.50	1.50
10	0.025	15.50	1.53	1.54	1.54	1.66	1.56	1.54	1.49	1.49	1.55	1.54
18	0.047	15.50	1.54	1.53	1.54	1.69	1.59	1.56	1.48	1.49	1.54	1.59
20	0.055	15.50	1.53	1.53	1.53	1.69	1.59	1.55	1.49	1.49	1.53	1.59
25	0.034	15.50	1.52	1.52	1.53	1.67	1.64	1.56	1.47	1.48	1.53	1.59
32	0.040	15.50	1.52	1.53	1.52	1.68	1.56	1.55	1.48	1.49	1.53	1.65
35	0.030	15.50	1.51	1.51	1.51	1.67	1.65	1.54	1.48	1.48	1.51	1.63
40	0.035	15.50	1.52	1.51	1.54	1.67	1.55	1.66	1.49	1.49	1.53	1.60
46q	0.047	15.80	1.56	1.56	1.56	1.72	1.57	1.51	1.57	1.55	1.56	1.65
50	0.055	15.80	1.56	1.56	1.56	1.73	1.57	1.56	1.58	1.56	1.56	1.59
55	0.047	15.80	1.53	1.52	1.53	1.69	1.69	1.55	1.55	1.52	1.54	1.63
58	0.040	15.80	1.52	1.52	1.53	1.71	1.70	1.54	1.60	1.52	1.54	1.59
65	0.060	15.80	1.55	1.55	1.55	1.75	1.58	1.58	1.56	1.55	1.56	1.58
70	0.052	15.80	1.55	1.55	1.55	1.76	1.56	1.70	1.58	1.54	1.58	1.70
73	0.037	15.80	1.55	1.55	1.56	1.77	1.55	1.59	1.57	1.56	1.56	1.58
80	0.060	15.80	1.55	1.55	1.56	1.78	1.57	1.53	1.55	1.46	1.53	1.69
87	0.082	15.80	1.54	1.57	1.55	1.72	1.79	1.76	1.52	1.48	1.54	1.72
90	0.052	15.80	1.55	1.55	1.58	1.74	1.59	1.55	1.56	1.47	1.63	1.61
94	0.064	15.80	1.56	1.57	1.56	1.77	1.65	1.57	1.53	1.49	1.58	1.57
101	0.059	15.80	1.56	1.55	1.55	1.77	1.61	1.59	1.50	1.55	1.57	1.56
108	0.035	15.80	1.54	1.54	1.55	1.81	1.56	1.57	1.59	1.55	1.57	1.56
115	0.030	14.20	1.55	1.51	1.58	*	1.54	1.51	1.66	1.52	1.69	1.65

* Cell 4 removed at cycle 112.